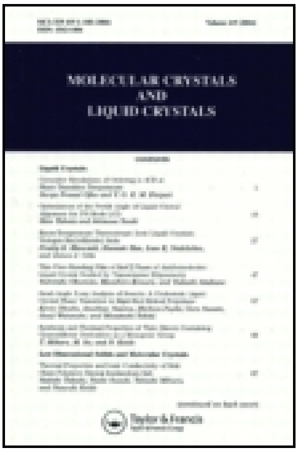

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INVESTIGATION OF RING STRUCTURES IN FREE-STANDING FERROELECTRIC FILMS BY AN IMAGE ANALYSING SYSTEM

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Abstract Free-standing ferroelectric films in a rotating electric field have been investigated. The spontaneous formation and the evolution of dark and bright rings were studied by an image analysing system. Area and width of the rings depend on the extent of the ring system. A quasi-stationary state is possible which is characterized by a ring creation rate of zero and by a defined quantity of rings. The evolution of the systems is mainly determined by the elastic properties of the ferroelectric liquid crystals.

INTRODUCTION

In free-standing films of smectic liquid crystals different types of defect formations induced by electric fields have been observed.[1,2] In ferroelectric liquid crystals (FLCs) systems of dark and bright rings can be spontaneously created by a rotating electric field in a four-electrode equipment.[3,4] The formation of these ring systems depends on the strength of the applied field E, the rotational frequency of the field ω (Figure 1), and the pitch p of the FLC.[5] The rings may be accepted as an arrangement of π-walls. Two different types of ring systems were observed: A full ring system which encloses the whole film area (region **C** in Figure 1), and small ring systems which occupy only a part of the film area (region **B** in Figure 1). Some small systems may be created simultaneously in the same free-standing film.

After the initial formation of a full system new rings are successively created in the rotating centre of the film. Their diameter increases, and the velocity of this increase depends on the field parameters.[5] The outside rings are destroyed near the film border at the substrate which holds the free-standing film. Usually, the creation rate of rings in the centre is higher than the reduction rate at the border. An accumulation of rings results. The

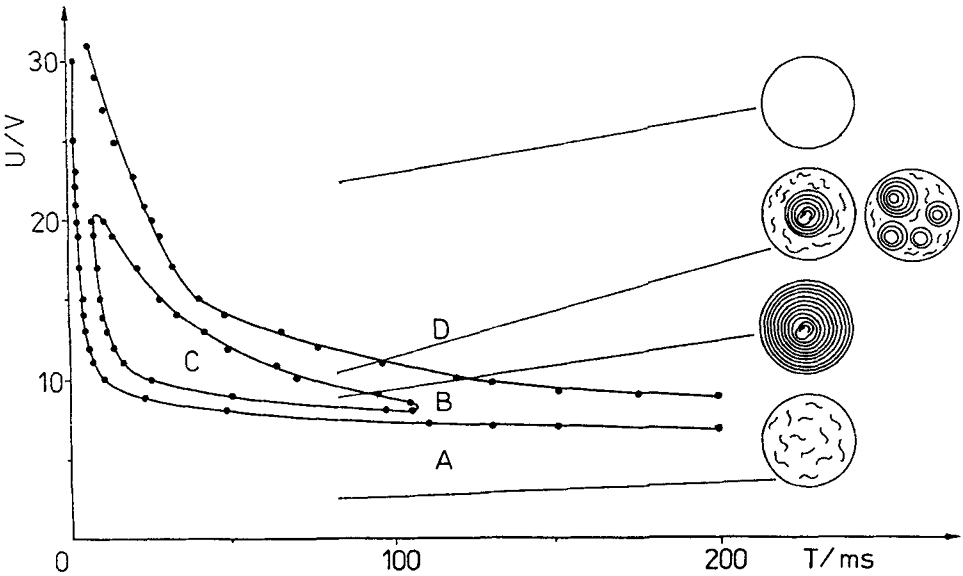

FIGURE 1 Spontaneously created structures in dependence on the applied voltage U and the period of field rotation T $(= 2\pi/\omega)$ for FLC mixture 15/2. **A** - schlieren texture; **B** - small ring systems; **C** - one ring system which encloses the whole film area; **D** - homogenous orientation.

velocity of increase of later created rings is reduced. In small ring systems new rings are also created in the middle of these systems. Their diameter increases, and the specific director order of the rings breaks down outside to a schlieren texture.

A theoretical treatment indicates that the formation and the evolution of structures show a quasi-soliton-like behaviour.[6] A complete theoretical description of the dynamical behaviour of ring systems is, probably, too complicated at the present state of knowledge. In this paper we study the evolution of structures in more detail to get further experimental informations. We investigate characteristic parameters of rings (e.g. area, width) in full as well as in small systems. Moreover, the ring accumulation process in full systems and its dependence on applied voltage and on frequency are studied. An image analysing system is used to obtain data from the microscopic pictures of ring formation.

EXPERIMENTAL

Free-standing films are prepared by carefully drawing FLC material across an circular

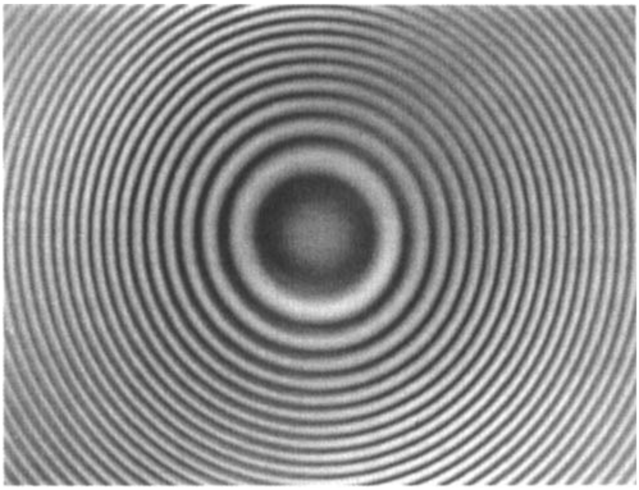

FIGURE 2 Videoprint of a full ring system; FLC mixture FE1, $U = 25$ V, $T = 1$ ms (24°C).

opening in a thin substrate (glass or other isolating material). The smectic layers are oriented parallel to the surface of the resulting film. In our experiments the film thickness was about 500 nm and the diameter 1 mm. Four electrodes are arranged perpendicular to each other on the substrate to apply a rotating electric field, which results from rectangular voltage impulses, parallel to the film surface. The potential sequence at the electrodes is $+U$, zero, $-U$, and zero.[3,4] The film takes up the whole area between the electrodes. The upper limit of the field strength is $E_{max} = 1$ kV/cm, and the frequency ω is 0.6 Hz ~ 16 kHz. We investigated two FLC mixtures which exhibit the SmC* phase at room temperature: 15/2 and FE1, both from MLU Halle, with a spontaneous polarization P_s of 34.7 and 11.3 nC/cm^2, respectively. The pitch values p at 24°C are 2.3 and 8.5 µm. Additionally, a mixture Mi7 is used ($P_s = 9.7$ nC/cm^2, $p = 2.1$ µm) which contains 79 wt.-% 90-917B (Fa. Merck) and 21 wt.-% FLC6430 (La Roche).

The experiments are carried out in a microscope between crossed polarizers. The microscope is equipped with a charge coupled device (CCD) camera with video recording of the microscopic pictures (Figure 2). The video signals are transferred into a personal computer. Then, a frame capturing is performed by the frame grabber DT2855 (Data Translation, Inc.). Intensity and contrast adjustments are possible during the capturing process. The images are saved into a file. The image processing is carried out with the

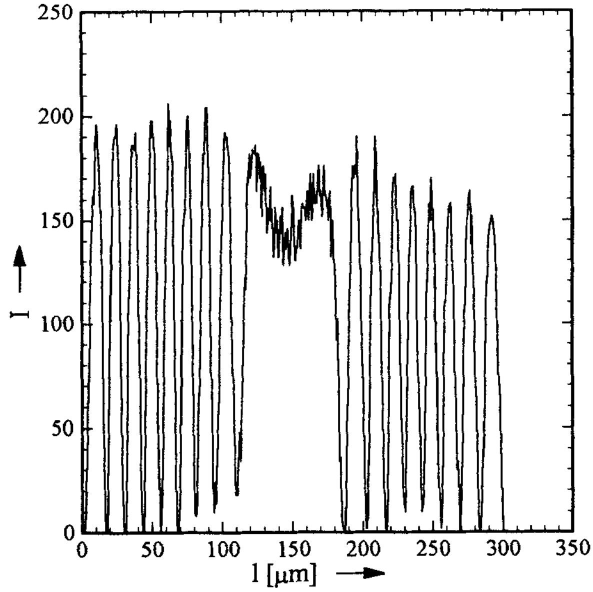

FIGURE 3 Intensity profile through a small ring system (intensity I versus the length l along the line of measurement); FLC mixture FE1, $U = 18$ V, $T = 2$ ms.

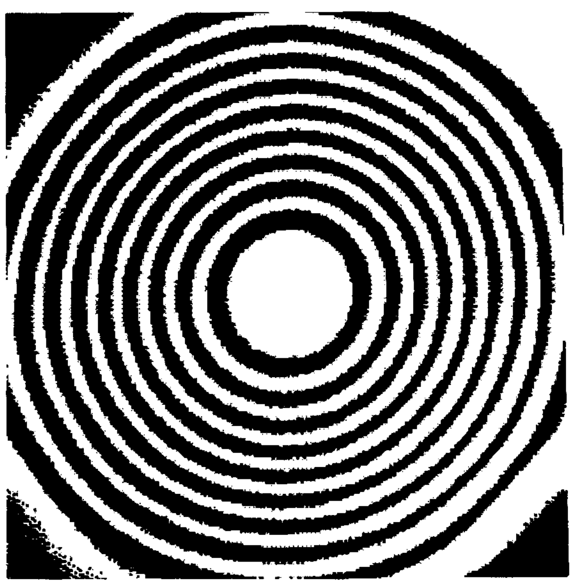

FIGURE 4 Processed video frame of the small ring system given in Figure 3.

software GLOBAL LAB® *Image*. Intensity profiles trough the ring systems (Figure 3) enable the measurement of the mean diameter (d) of the rings. After an adjustment of the intensity level, which separates the dark and the bright rings, processed video frames are achieved (Figure 4). In these video frames different measurements are possible: area of the rings (A), ring perimeter (P), width of rings in two orthogonal directions (w_x, w_y).

RESULTS

The intensity profiles through the ring systems (Figure 3) show a continuous change of transmission between maxima and minima. This corresponds to a continuous rotation of the projection of the director on the layer plane. This behaviour is in agreement with the assumption that a ring system is an arrangement of π-walls.

After the initial formation of the ring system new rings are created in the center. In full ring systems the area A of the first rings (N = 1...5, with N - ring number) decreases with increasing N, as shown in Figure 5. Far away from the centre (N = 6...) the area is constant. Because of the creation process the area of the rotating centre (N = 0) is changing with time between a minimum and a maximum value. Therefore, in Figure 5 the measured area of the centre is out of the general trend. The perimeter of the rings increases nearly linear, with a steeper increase near the centre. The ring width measured in two orthogonal directions shows a continuous decrease with increasing N.

In small ring systems (Figure 6) A increases continuously. The rotating centre is again out of the trend. The perimeter is also increasing. The behaviour of the ring width is similar to that of the area in the case of full ring systems: Decreasing width in the rings near the central part (N = 1...5); a constant value outside the centre (N = 6...).

Because of the accumulation process in full systems the creation rate of rings decreases down to zero, and the rotation of the centre stops. A quasi-stationary state results. The ring structures are without any visible motion, and the centre does not show any changes. In the quasi-stationary state which is given by the parameters $\bar{U}$ and $\bar{\omega}$ the ring system contains a defined quantity of rings N_{max} (Figure 7). N_{max} depends linearly on the value of $\bar{U}$. Because of this relation and the constant film area, the diameter d of the rings depends also on $\bar{U}$. In Figure 8 this behaviour is drawn for different rings with the number N. The fitted curves obey the relation: $d = m/\bar{U} + n$; where m and n are fitting

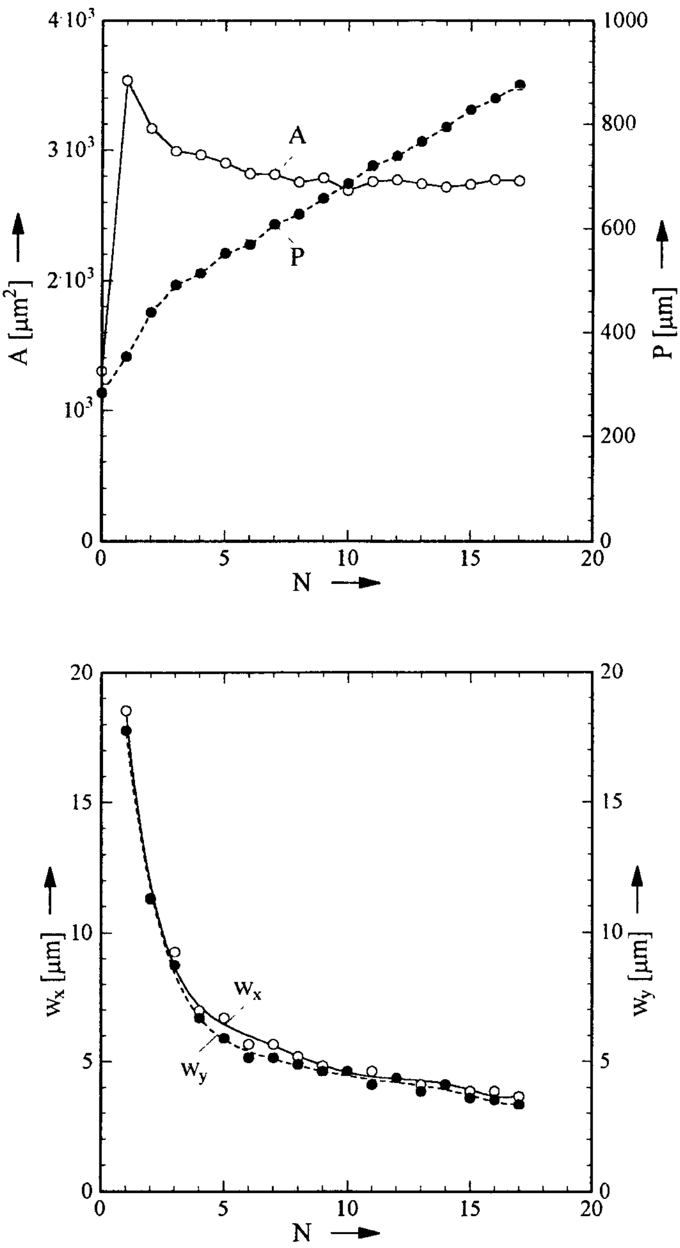

FIGURE 5 Area (A), perimeter (P), and width of rings (w_x, w_y) in a full ring system; N - number of rings counted from the centre; the experimental parameters are given in Figure 2.

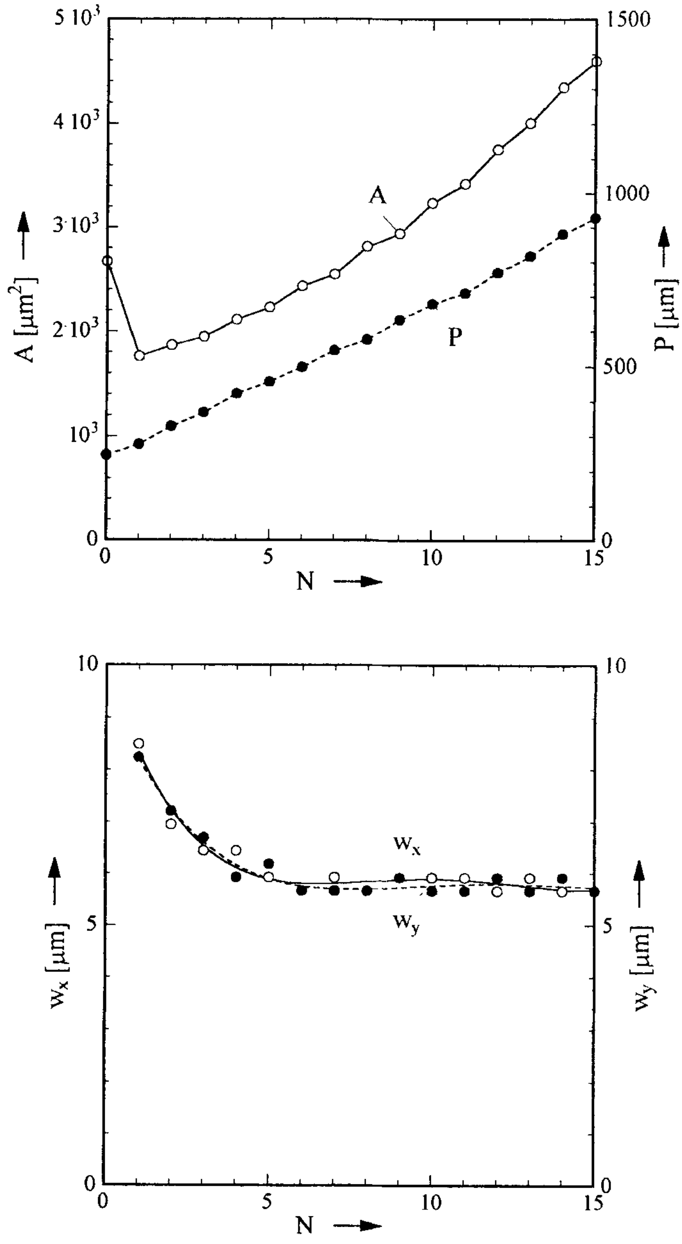

FIGURE 6 Area, perimeter, and width of rings in a small system; the experimental parameters are given in Figure 3.

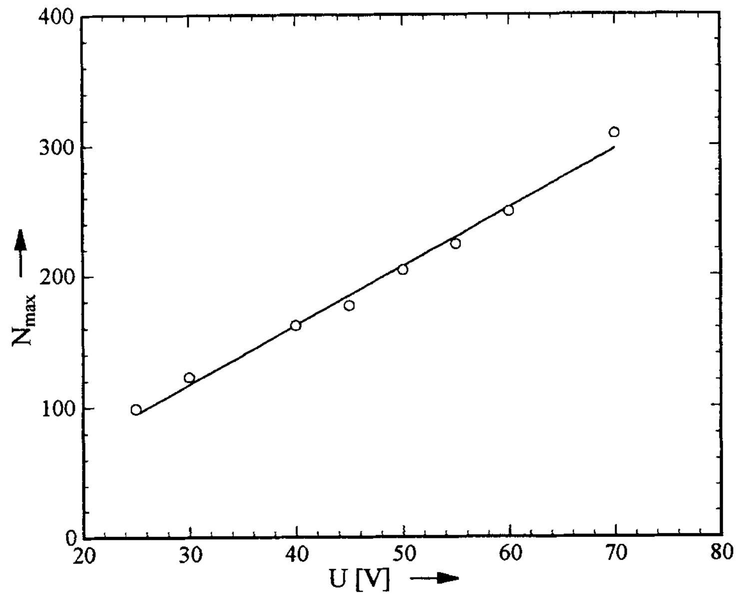

FIGURE 7 Dependence of quantity of rings in a full system (N_{max}) on the applied voltage at quasi-stationary conditions.

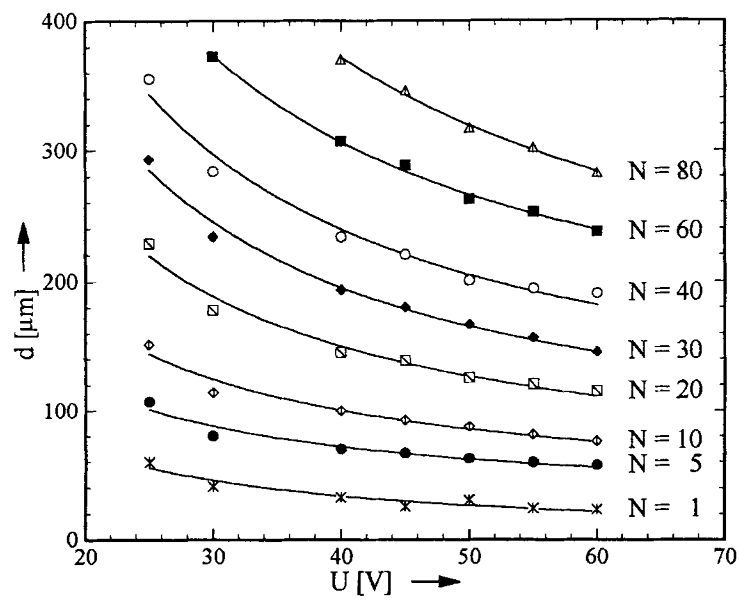

FIGURE 8 Diameter d of different rings on the applied voltage at quasi-stationary conditions.

parameters.

If the voltage applied onto a ring system in the quasi-stationary state is increased $\{\bar{U}+\Delta U,\ \bar{\omega}\}$, the centre of the system rotates again in the direction of field rotation, and new rings are created (Figure 9). Then, the creation rate decreases again until a new quasi-stationary state is established. At $\{\bar{U}-\Delta U,\ \bar{\omega}\}$ the centre rotates against the field rotation. A reduction of rings can be observed in the centre which is the inverse to the creation process. These changes in the ring system becomes slower and slower. They stop at a new quasi-stationary state. The case $\{\bar{U},\ \bar{\omega}+\Delta\omega\}$ corresponds to $\{\bar{U}-\Delta U,\ \bar{\omega}\}$, and $\{\bar{U},\ \bar{\omega}-\Delta\omega\}$ is similar to the case $\{\bar{U}+\Delta U,\ \bar{\omega}\}$.

CONCLUSIONS

In the experiments we were able to get quantitative informations on ring structures by the use of an image analysing system. The derived results give rise to the following conclusions: In full ring systems an accumulation of rings takes place which starts at the border of the sample. The elastic strains from the director distortions in the π-walls increase because of the decreasing by time width of the rings. In the quasi-stationary state the field-induced creation of new rings in the centre is suppressed by these elastic forces. The width (w_x, w_y) of those rings which are outside of the central part of the system have probably to decrease at increasing ring number, and the area should be fixed, to hold the density of elastic strains in every ring constant.

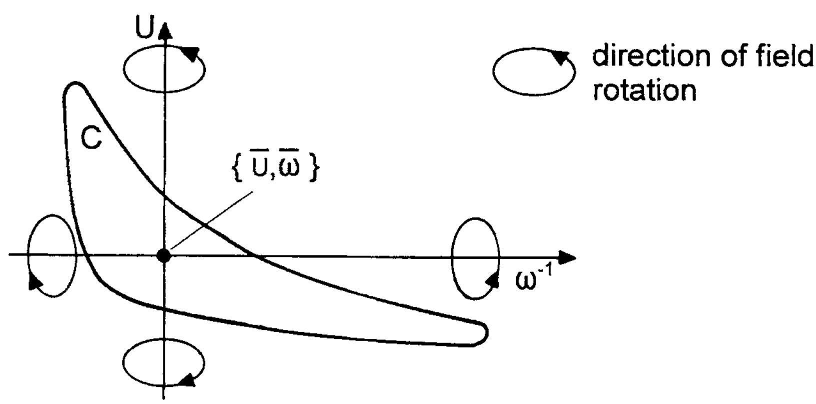

FIGURE 9 Schematic representation of the effect of change of field parameters in the quasi-stationary state.

The region **C** of the U-ω-diagram was derived from the parameters of ring systems at the initial structure formation. We found that inside of the region **C** a quasi-stationary state is possible which is characterized by a ring creation rate of zero and by a defined quantity of rings. A change of the field parameters causes the creation or the reduction of rings in the centre until a new quasi-stationary state is established.

In small systems the ring width is constant, and the area increases outside the centre. In these systems which are free of border influences the local elastic distortion in the π-wall give rise to a regular spaced pattern.

The initial creation of ring systems in a rotating electric field shows a quasi-soliton-like behaviour.[6] The further evolution of the systems is mainly determined by the elastic strains which result from the limited area of the sample. These strains have a strong influence on the size and on the creation/reduction process of rings. They are also responsible for the geometrical shape of the π-walls. If the free-standing film is not circular, but a rectangular or a square one, the π-walls outside the central part of the film adopt these shapes.[5]

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